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Nutrient reference values for 'BRS Platina' banana in improved fertility soils

Valores de referência nutricional para bananeira 'BRS Platina' em solos de fertilidade construída

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ABSTRACT

Reference values of leaf nutrient contents are essential for nutritional assessment of plants. The objective was to establish nutritional reference values for 'BRS Platina' banana in improved fertility soil, using the sufficiency range (SR), border Line (BL) and mathematical chance (MCh) methods, in addition to the critical level obtained by the reduced normal distribution (CLz). The study was carried out in Guanambi-BA, considering nutrient contents and yields of an experiment arranged in randomized blocks, 5 x 6 factorial scheme, with five doses of K_2O (0, 200, 400, 600 and 800 kg ha^{-1}) supplied with fertilizers for organic management and six sampling times (210; 390; 570; 750; 930 and 1,110 days after planting), totaling 90 plots. Plots with high yield, ≥ 38.40 t ha^{-1}, formed the reference population and plots with yield ≥ 47.43 t ha^{-1} formed the reference subpopulation. There was convergence between the optimal values obtained by the methods evaluated. Therefore, the reference values adjusted by the SR, BL, MCh and CLz methods can be used with assertiveness to interpret the foliar analysis of the 'BRS Platina' banana in improved fertility soils. Furthermore, among these, MCh stands out as it provides narrower optimal ranges.

Index terms: *Musa spp*.; diagnostic methods; nutritional status.

RESUMO

Valores de referência dos teores foliares são essenciais para avaliação nutricional das plantas. Objetivou-se estabelecer valores de referência nutricional para a bananeira 'BRS Platina' em solo de fertilidade construída, mediante a utilização dos métodos faixa de suficiência (SR), linha de fronteira (BL) e chance matemática (MCh), além do nível crítico obtido pela distribuição normal reduzida (CLz). O estudo foi realizado em Guanambi-BA, considerando teores de nutrientes e produtividades de experimento arranjado em blocos casualizados, esquema fatorial 5 x 6, cinco doses de K_2O (0, 200, 400, 600 e 800 kg ha^{-1}) supridas com fertilizantes para manejo orgânico e seis épocas de amostragem (210; 390; 570; 750; 930 e 1.110 dias após plantio), totalizando 90 parcelas. Parcelas de alta produtividade, ≥ 38,40 t ha^{-1} formaram a população de referência e ≥ 47,43 t ha^{-1} subpopulação de referência. Houve convergência entre os valores ótimos obtidos pelos métodos avaliados. Portanto, os valores de referência ajustados pelos métodos SR, BL, MCh e CLz podem ser usados com assertividade para interpretação da análise foliar da bananeira 'BRS Platina' em solos de fertilidade construída. Ademais, dentre esses, a MCh se destaca pois proporciona faixas ótimas mais estreitas.

Termos para indexação: *Musa* spp.; métodos diagnósticos; estado nutricional.

INTRODUCTION

Banana is the most produced fruit in the world and its cultivation is an important agricultural activity in Brazil. Despite this, the average yield of this crop is low, 14.6 t ha^{-1}. This is associated with the cultivated genotypes, nutritional (Guimarães; Deus, 2021) and non-nutritional problems, and biotic, climatic and management factors (Rodrigues Filho; Neves; Donato, 2021).

Adequate nutrition of banana plants depends on the availability of nutrients in the rhizosphere, statically predicted by soil analysis, and on the consequent absorption by the plant, evaluated by tissue analysis, which better reflects the dynamics over the whole process. This suggests that leaf analysis interpretation requires the adjustment of specific, local norms or reference values, to the detriment of universal norms (Rodrigues Filho et al., 2021a).

For 'Prata-Anã' banana, in different regions, norms were adjusted by methods involving univariate relationships between nutrients, such as Sufficiency Range, SR (Pereira et al., 2015; Silva, 2015), Critical Level, CLz (Carvalho Júnior et al., 2019) and Boundary Line, BL (Rodrigues Filho et al., 2021b); bivariate relationships, such as Diagnosis and Recommendation Integrated System, DRIS (Pereira et al., 2015; Rodrigues Filho et al., 2021a; Silva; Carvalho, 2006) and Balance Indices of Kenworthy, BIKW (Rodrigues Filho et al., 2021b); multivariate relationships, such as Compositional Nutrient Diagnosis, CND (Lima Neto et al., 2021); and machine learning, CoDa (Lima Neto et al., 2020). In addition, the Mathematical Chance, MCh (Wadt et al., 1998) was also applied, which according to the authors allows the use of data from leaf analysis and yield of commercial plantations or calibration tests as long as they are robust.

In this context, univariate methods are widely used. Mainly because they present critical, great levels and great tracks that are easy to interpret. In addition, methods that support monitoring data from commercial crops and not just from controlled trials have gained great prominence, as is the case of the Border Line (Walworth; Letzsch; Sumner, 1986), based on the mathematical description of the border line of nutritional contents, plotted in relation to crop yield, as well as mathematical chance (Wadt et al., 1998), based on probabilistic calculations. Therefore, traditional methods widely used, such as NC and FS, were adjusted, making it possible, currently, to determine norms from data from commercial crops, as proposed by (Maia; Morais; Oliveira, 2001) for NC, through from the reduced normal distribution, and by (Martinez et al., 2003) for the FS, using the critical range technique.

However, there is a demand for norms for new genotypes such as 'BRS Platina', which has yield equivalent to that of its progenitor 'Prata-Anã' and is resistant to fusariosis (Lichtemberg et al., 2021), but with different nutritional requirements and efficiencies (Silva et al., 2014). Moreover, it is important to conduct studies on soils with fertility improved by anthropic actions (Marques et al., 2022), a common situation in well-managed banana plantations.

Thus, the objective was to establish nutritional reference values for 'BRS Platina' banana in improved fertility soil, using the Sufficiency Range (SR), Border Line (BL) and Mathematical Chance (MCh) methods, in addition to of the Critical Level obtained by the reduced normal distribution (CLz).

MATERIAL AND METHODS

The study was conducted at the Federal Institute of Bahia, Guanambi campus, BA, Brazil (14°17'38" S, 42°41'42" W, average altitude of 525 m). The climate is hot and dry semi-arid, with well-defined dry season in winter and rainy season between October and March. The average annual rainfall is 672 mm and the average annual temperature is 26 ºC.

The soil, originally classified as *Latossolo Vermelho-Amarelo distrófico*, with medium texture (Santos et al., 2018), corresponds to Oxisol. However, after correction, with two decades of applications of organic and chemical fertilizers and incorporation of crop residues, its fertility has been improved (Marques et al., 2022) and its nutrient contents and base saturation were changed from a dystrophic to a eutrophic condition (Table 1).

Table 1: Means and standard deviations of chemical attributes of the soil with improved fertility cultivated with 'BRS Platina' banana before transplanting. Guanambi, BA.

Sampling	pH[1]	OM[2]	P[3]	K[3]	Na[3]	Ca[4]	Mg[4]	Al[4]	H+Al[5]	SB
m		$g\ kg^{-1}$	---------- $mg\ dm^{-3}$ ---------		----------------------------- $cmol_c\ dm^{-3}$ ------------------------------					
0.0-0.2	7.4±0.2	12.3±2.5	468.3±32.2	493.0±46.8	0.1±0	4.6±0.5	1.7±0.1	0	0.8±0	7.6±0.4
0.2-0.4	7.3±0.1	1.7±0.6	229.1±67.5	372.0±61.5	0.1±0	3.5±0.3	1.1±0.2	0	0.8±0.1	5.7±0.4
Sampling	T	V	m	B[6]	Cu[3]	Fe[3]	Mn[3]	Zn[3]	Prem[7]	EC
m	$cmol_c\ dm^{-3}$	---------- % ----------		-------------------------- $mg\ dm^{-3}$ --------------------------					$mg\ L^{-1}$	$ds\ m^{-1}$
0.0-0.2	8.4±0.5	91.0±0	0	0.9±0.3	2.2±0.3	22.3±6.2	46.5±1.3	40.8±11.8	43.6±1.0	1.5±0.2
0.2-0.4	6.5±0.4	88.7±0.6	0	1.0±0.1	1.2±0.1	26.8±7.6	27.7±1.1	8.7±2.4	42.2±2.5	1.3±0.2

Source: Marques et al. (2022) modified. [1]pH in water; [2]colorimetry; [3]Mehlich-1 extraction; [4]1 mol L^{-1} KCl; [5]pH SMP (Shoemaker-McLean-Pratt method); [6]$BaCl_2$ extractant; [7]equilibrium solution of P; OM - organic matter; SB – sum of bases; T - cation exchange capacity at pH 7; V - base saturation; m - aluminum saturation; Prem - remaining phosphorus; EC - electrical conductivity.

The database used contained the contents of nutrients (N, P, K, S, Ca, Mg, B, Cu, Fe, Mn, Zn) and Na in the leaves and bunch yields (BY) obtained from an experiment with 'BRS Platina' banana, AAAB hybrid derived from 'Prata-Anã', planted at 2.5 m x 2.0 m spacing (2,000 plants ha^{-1}), irrigated by microsprinkler, conducted during four production cycles with a similar average yield of 38.40 ± 8.6 t ha^{-1} between cycles (Marques et al., 2022). The sampled population consisted of 90 plots (n = 90) arranged in a randomized block design in a 5 × 6 factorial scheme, corresponding to five doses of K_2O (0, 200, 400, 600 and 800 kg ha^{-1}), supplied with fertilizers for organic management (cattle manure - 2.5 g kg^{-1} of K_2O and rock powder - 30 g kg^{-1} of K_2O), six leaf sampling times (210; 390; 570; 750; 930 and 1,110 days after planting) and three replicates, plots with six usable plants and complete border.

Leaf tissue was sampled according to Rodrigues et al. (2010). Nutrient contents were determined and yields were estimated in t ha^{-1} $cycle^{-1}$ by weighing the bunches during the harvests of each plot. The results of leaf and yield analyses were organized and processed in a Microsoft Excel® spreadsheet.

According to Marques et al. (2022), the cattle manure used showed on dry basis at 65 °C, on average, moisture of 16.72%, organic matter of 637.3 g kg^{-1}, pH of 7.42, density of 0.38 g cm^{-3} and the following contents of macronutrients (g kg^{-1}): Ca = 1.7, Mg = 0.2, K = 2.5, N = 5.2, S = 2.3 and P = 4.7; and micronutrients (mg kg^{-1}): B = 2.1; Cu = 45.2; Zn = 200.5; Mn = 391.8 and Fe = 1,932.4 (EPA 3051 / APHA 3120B). The rock powder, natural earth from Ipirá, Naturalplus® from Terra Produtiva Mineradora Ltda., contained 30.0 g kg^{-1} of K_2O (total), 10.0 g kg^{-1} of P_2O_5, 52.0 g kg^{-1} of CaO, 30.0 g kg^{-1} of MgO, 63.0 g kg^{-1} of Fe_2O_3, 1.5 g kg^{-1} of MnO, 630 g kg^{-1} of SiO_2, 69 mg kg^{-1} of Zn, 127 mg kg^{-1} of Cu and 5 mg kg^{-1} of OM.

Fertilizer doses were split into six annual applications. Foliar applications of B and Zn were also performed until the flowering of the first production cycle; from the second cycle onwards, B, Zn and Cu were applied via rhizome of the thinned shoot, and Mg was applied in the soil (Marques et al., 2022).

The methods used to determine the reference values were: Sufficiency Range (SR), Critical Level by Reduced Normal Distribution (CLz), Boundary Line (BL) and Mathematical Chance (MCh). The data set was separated into low-yielding population (LYP) and high-yielding population (HYP), below and above 38.4 t ha^{-1} $cycle^{-1}$, respectively. As used by Alves et al. (2019), the HYP was considered for SR. For MCh, the HYP, mean of 44.91 t ha^{-1} $cycle^{-1}$ (n= 49), was subdivided into a reference subpopulation, based on the mean + 0.5 standard deviation, greater than or equal to 47.43 t ha^{-1} $cycle^{-1}$ (n=16).

The SRs were determined by the equation: SR = $\bar{x} \pm kS\bar{x}$, where $\bar{x}$ = average content of each nutrient in the leaf; $S\bar{x}$ = standard deviation of the mean; and k = correction factor to adjust the sufficiency ranges, avoiding very wide intervals, as used by Alves et al. (2019). The values of k considered the coefficient of variation (CV) of each nutrient: k = 1.0 for nutrients with CV below 20%; k = 0.8 for CV between 20.01 and 40%; k = 0.6 for CV between 40.01 and 80%; and k = 0.4 for CV greater than 80%. Thus, five interpretative classes were adjusted for the nutrient contents in banana leaves: deficient (DEF), < $(\bar{x} - 2kS\bar{x})$; tending to sufficient (TSF), ≥ $(\bar{x} - 2kS\bar{x})$ and < $(\bar{x} - kS\bar{x})$; sufficient (SUF), SR ≥ $(\bar{x} - kS\bar{x})$ and < $(\bar{x} + kS\bar{x})$; high (H), ≥ $(\bar{x}+kS\bar{x})$ and < $(\bar{x} +2kS\bar{x})$ and tending to excessive (TEX), ≥ $(\bar{x}+2kS\bar{x})$.

The CLz values of the nutrient contents were determined by the reduced normal distribution method, as used by Alves et al. (2019): $CLz_{(i)} = (1.281552 \cdot S\bar{x}_1 + \bar{x}_1) / (1.281552 \cdot S\bar{x}_2 + \bar{x}_2)$; where, $CLz_{(i)}$ is the critical level of the nutrient i; $S\bar{x}_1$ and $\bar{x}_1$ are the standard deviation and the mean of BY; and $S\bar{x}_2$ and $\bar{x}_2$ are the standard deviation and mean of Q, which is defined as the ratio between BY and $n_{(i)}$ ($Q = BY/n_{(i)}$); where $n_{(i)}$ is the nutrient content used.

To apply the BL method, BY values were related to the leaf nutrient contents, through scatter plots. Data points located at the top edge of the scatter plot (X, Y) were selected, forming a boundary line. Each data point on the line represents the highest yield at a corresponding nutrient concentration. A regression equation fitted to the potential nutrient-response curve (Rodrigues Filho et al., 2021b) was used to determine the reference values.

Then, the BL equations were derived and the first derivative was equaled to zero to obtain the optimal levels by the BL method (OL_{BL}) of the leaf contents of each nutrient corresponding to the maximum point on the BL curve. These values were replaced in the respective equations to estimate the maximum values of bunch yield (BY_{MP}) on the 'y' axis, and multiplied by 0.7 and 0.9 to obtain the 'y' values corresponding to 70 and 90% of yield, which were then used to estimate the sufficiency ranges for each nutrient. The lower (LL) and upper (UL) limits were determined based on the following interpretive categories: deficient (BY <70%, to the left of the maximum), tending to sufficient (70% ≤ BY < 90%, to the left of the maximum), sufficient (90%, to the left of the maximum, ≤ BY > 90%, to the right of the maximum), high (90% > BY ≥ 70%, to the right of the maximum), and tending to excessive (BY < 70%, to the right of the maximum).

The adjustment of the classes by MCh (Wadt et al., 1998) followed Alves et al. (2019); for each nutrient, the contents were ordered and distributed in number of classes (i), corresponding to the square root of the number of observations (n), whose intervals of each class were calculated by dividing the amplitude of the nutrient contents by the number of predefined classes. In each class, the mathematical chance (MCh) was calculated by the equation: $MCh_{(i)} = [(MCh(A_{(i)}/A) \times MCh(A_{(i)}/C_{(i)})]^{0.5}$, where: $MCh_{(i)}$ = mathematical chance in class "i"; MCh $(A_{(i)}/A) = P(A_{(i)}/A) \times BY_{(i)}$; $P(A_{(i)}/A)$ = frequency of high-yielding plots in class "i", relative to the overall total of high-yielding plots; $BY_{(i)}$= average yield of high-yielding plots in class *i* (t ha^{-1}); MCh $(A_{(i)}/C_{(i)}) = P(A_{(i)}/C_{(i)}) \times BY_{(i)}$; and $P(A_{(i)}/C_{(i)})$ = frequency of high-yielding plots of class *i*, relative to the overall total of plots in class "i".

The optimal ranges for each nutrient were located between the lower ($LL_{(i)}$) and upper ($UL_{(i)}$) limits of the classes with the highest MCh. As adopted by Alves et al. (2019), the highest total frequency of plots in class *i* and the highest frequency of plots with highest BY (≥ 47.43 t ha^{-1}) in class *i* were also considered. Subsequently, the optimal levels (OL_{MCh}) of the nutrients were estimated by the median of the threshold values of the selected classes.

RESULTS AND DISCUSSION

Of the 90 plots with 'BRS Platina' banana, 49 (54%) were above the average yield (≥ 38.4 t ha^{-1}), composing the HYP. Of these, 16 (32%) formed the reference subpopulation for MCh (≥ 47.43 t ha^{-1}). 74% of the total expressed yield > 32 t ha^{-1}, considered high for 'Prata-Anã' in northern Minas Gerais (Silva; Pacheco; Costa, 2007) and in agreement with results found in Bahia and Ceará (Rodrigues Filho et al., 2021a). These yields are consistent with the high soil fertility (Table 1), resulting from the applications of fertilizers over time, especially manure, because organic matter is an indicator of soil quality and determinant for yield (Silva, 2021).

Sufficiency Range (SR)

The reference values by the FS technique, and the values of mean, standard deviation and coefficient of variation of each nutrient, are in Table 2. As for the nutritional reference values, it is possible to observe that practically all nutrients, with the exception of Mn , showed sufficient (optimal) range limits above those established by Silva (2015), in the northern region of Minas Gerais. Such results indicate good agreement of values in relation to high soil fertility, as well as the difference between the genotypes studied.

The coefficients of variation (CV) for the contents of macronutrients, except Ca, were lower than 25%. For micronutrients, except B, the coefficients of variation were higher, with Mn (49.9%) showing the greatest variability, corroborating Rodrigues Filho et al. (2021a). This is due to the complexity of its dynamics in the soil, influenced by pH, reduction potential, parent material, content and quality of organic matter and clay (Rodrigues Filho et al., 2021b).

Border Line (BL)

Significant quadratic equations were fitted between BY and concentrations of nutrients in the leaves of 'BRS Platina' banana by BL, with R^2 values from 0.62 to 0.99 (Figure 1A-L), whose derivation resulted in the reference values (Table 3). It can observed that this method promoted the lowest amplitudes of the intervals of sufficient range for the nutrients (K, Mg, Cu, Mn, Zn and Na) compared to those established by Silva (2015).

The advantage of BL compared to the other methods tested in nutritional diagnosis studies is related to its high predictive capacity in data adjustment, which allows estimating the highest achievable yield (Ali, 2018). Rodrigues Filho et al. (2021b) verified greater accuracy in the norms obtained using BL to evaluate the nutritional status of 'Prata-Anã' banana cultivated under two environmental conditions.

Mathematical Chance (MCh)

Seven classes were established for ChM, however, to obtain yields higher than 47.43 t ha^{-1}, most nutrients showed the highest MCh from class 4 (Table 4). The optimal ranges for K (31.5 to 35.0 g kg^{-1}), S (2.0 to 2.6 g kg^{-1}) and Mn (73.1 to 123.7 mg kg^{-1}) were obtained between classes 4 and 5. For N (25.7 to 32.3 g kg^{-1}) and P (1.9 to 2.5 g kg^{-1}), the highest values were found in the limits between classes 4 and 6. For Ca, Mg and Fe, the highest MCh values were between classes 5 and 6, with the ranges between 5.1 and 7.4 g kg^{-1}, 3.7 and 4.6 g kg^{-1} and 85.7 and 158.2 mg kg^{-1}, respectively.

B showed, for most classes, high and uniform values of MCh. This fact resulted in the largest interval between the classes observed (1 to 6) and in the greatest amplitude of the values among the evaluated methods (17.6 to 39.9 mg kg^{-1}) (Table 5). Cu and Zn were the nutrients with the highest MCh defined in a single class, 6 (5.5 and 7.1 mg kg^{-1}) and 7 (12.2 and 20.0 mg kg^{-1}), respectively. For Na, the optimal range, 18.3 to 36.5 g kg^{-1}, was located between classes 6 and 7.

Table 2: Mean, standard deviation, coefficient of variation and reference values estimated using the sufficiency range (SR) technique, for interpretation of leaf concentrations of nutrients and Na in 'BRS Platina' banana in improved fertility soil. Guanambi, BA.

Nut	Reference values					1	S[1]	CV[1]
	DEF	TSF	SUF	H	TEX			
	g kg $^{-1}$							%
N	<22.9	22.9 – 26.7	26.7 – 34.2	34.2 – 37.9	>37.9	30.4	3.8	12.4
P	<1.6	1.6 – 1.9	1.9 – 2.5	2.5 – 2.8	>2.8	2.2	0.3	13.7
K	<28.5	28.5 – 31.2	31.2 – 36.6	36.6 – 39.3	>39.3	33.9	2.7	7.9
Ca	<4.2	4.2 – 5.6	5.6 – 8.4	8.4 – 9.8	>9.8	7	1.8	25.3
Mg	<3.4	3.4 – 3.9	3.9 – 4.9	4.9 – 5.4	>5.4	4.4	0.6	13.9
S	<1.6	1.6 – 2.0	2.0 – 3.0	3.0 – 3.5	>3.5	2.5	0.5	19
	mg kg $^{-1}$							%
B	<16.5	16.5 – 21.8	21.8 – 32.5	32.5 – 37.8	>37.8	27.2	6.7	24.6
Cu	<3.6	3.6 – 5.5	5.5 – 9.4	9.4 – 11.4	>11.4	7.5	2.5	32.8
Fe	<48.8	48.8 – 87.7	87.7 – 165.5	165.5 – 204.4	>204.4	126.6	48.6	38.4
Mn	<31.4	31.4 – 54.9	54.9 – 1018	101.8 – 125.3	>125.3	78.3	39.1	49.9
Zn	<9.8	9.8 – 15.3	15.3 – 26.2	26.2 – 31.6	>31.6	20.7	9.1	43.9
Na	<12.2	12.2 – 22.6	22.6 – 43.4	43.4 – 53.8	>53.8	33	13	39.3

Nut: Nutrients and Na; [1]: Mean, S: standard deviation and CV: coefficient of variation; n=49. DEF: deficient; TSF: tending to sufficient; SUF: sufficient; H: high; and TEX: tending to excessive.

In general, MCh resulted in the lowest amplitudes of the norms, for most nutrients, except B and Mn, compared to the evaluated methods (Table 5). This is justified because the reference subpopulation was used for MCh, thus more uniform, evidenced by the decrease in coefficients of variation (Tables 2 and 4): for BY from 11.20 to 4.36%, N (12.35 to 8.60%), P (13.66 to 8.40%), K (7.91 to 5.77%), Ca (25.27 to 17.70%), Mg (13.90 to 9.90%), Cu (32.80 to 21.72%), Fe (38.42 to 29.85%), Zn (43.88 to 11.31%) and Na (39.34 to 25.19%) and stability for S (19.04 to 19.40%), B (24.59 to 25.26%) and Mn (49.94 to 49.87%). Narrower norms allow greater accuracy in interpretation, reducing the chance of low-yielding plantations with levels within the normal range (Serra et al., 2010). Thus, MCh is more suitable for interpretation of leaf analyses of 'BRS Platina' banana in improved fertility soils.

Optimal Ranges

The optimal (sufficient) ranges obtained by SR (Table 2), BL (Table 3) and MCh (Table 4), for 'BRS Platina', progeny, compared with the current literature for 'Prata-Anã' banana, progenitor (Table 5), in Bahia using BL (Rodrigues Filho et al., 2021b) and in the North of Minas Gerais using SR (Silva, 2015), regions with some similarity to the environmental conditions of the present study, showed in general, except for Mn, Zn and Na, increments in the lower and upper limits. These increments were much higher compared to the values adjusted for Ponto Novo, Bahia (Rodrigues Filho et al., 2021b), and may be close to those for northern Minas Gerais (Silva, 2015), a region more similar to that of the present study.

The highest values of the observed limits are associated with the improved fertility of the soil, which increases the availability of nutrients, contributes to soil-root transport and their consequent absorption and accumulation in plants, which can result in luxury consumption. These higher values are also related to genotypes because, despite being progenitor and progeny, they differ in terms of nutritional requirements and efficiencies (Silva et al., 2014). These authors observed, in nutrient solution, higher levels of N, P, K, Mg and S, and similar levels of Ca in leaves of 'BRS Platina' banana compared to 'Prata-Anã' banana, although in the field under environmental conditions similar to those of the present study Donato et al. (2010) found similar levels of N, P, Ca and S, higher levels K and lower levels of Mg.

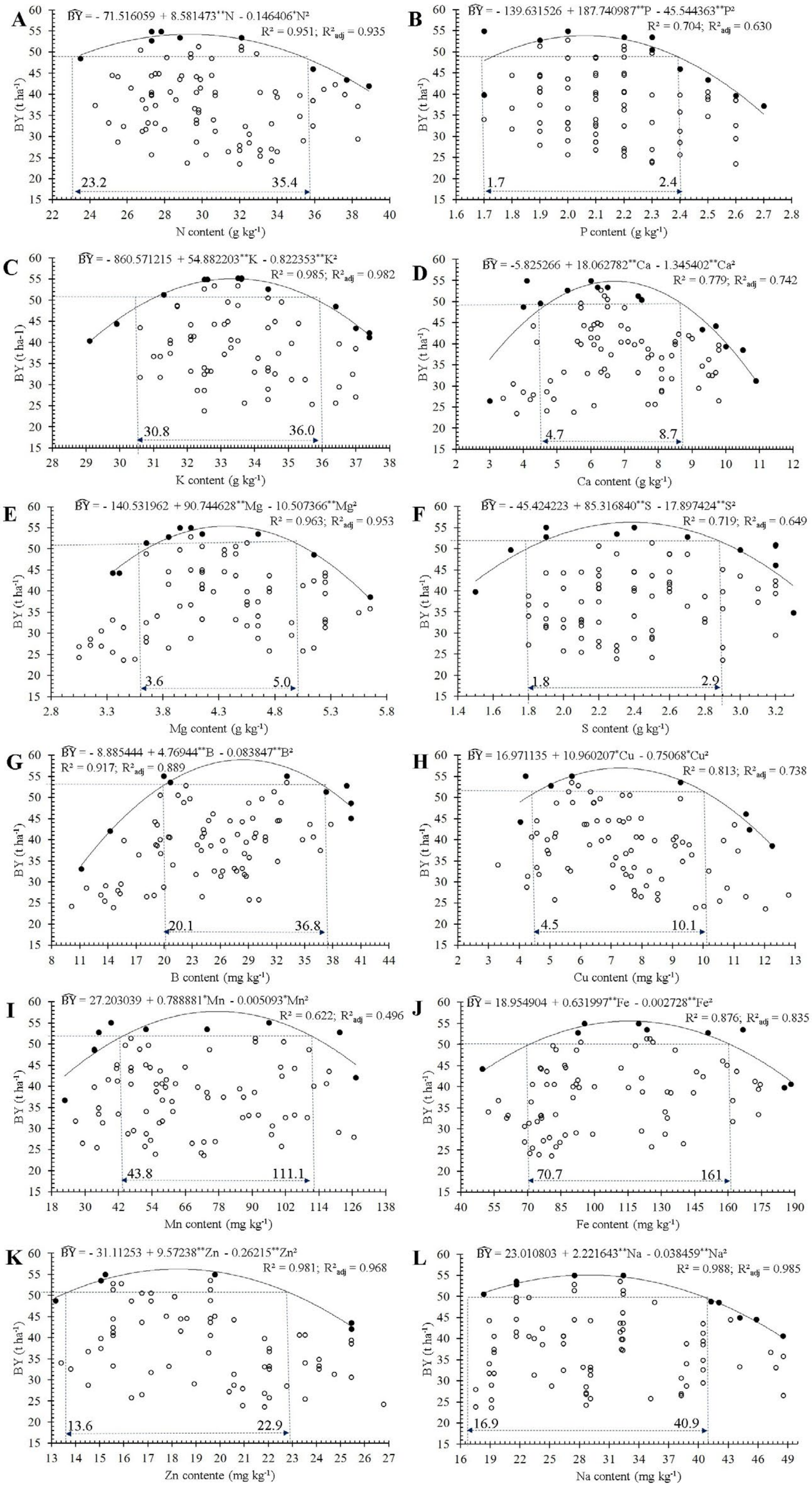

Figure 1: Boundary line (BL) fitted between bunch yield (BY) and leaf concentrations of N (A), P (B), K (C), Ca (D), Mg (E), S (F), B (G), Cu (H), Mn (I), Fe (J), Zn (K) and Na (L) of 'BRS Platina' banana in improved fertility soil. Guanambi, BA. **Significant (p ≤ 0.01) by t-test. R^2_{adj} = adjusted coefficient of determination.

Table 3: Estimation of maximum yield and corresponding optimal levels, as well as reference values by the Boundary Line (BL) method for interpretation of leaf concentrations of nutrients and Na in 'BRS Platina' banana in improved fertility soil. Guanambi, BA.

Nut	BY_{MP}	OL_{BL}	Reference values				
			DEF	TSF	SUF	H	TEX
			BY< 70%	70% ≤ BY< 90%	90%≤BY>90%	90%>BY≥70%	BY<70%
	t ha^{-1} cycle^{-1}	g kg^{-1}					
N	54.2	29.3	< 18.8	18.8 - 23.2	23.2 - 35.4	35.4 – 39.8	> 39.8
P	53.8	2.1	< 1.5	1.5 - 1.7	1.7 - 2.4	2.4 – 2.7	> 2.7
K	55.1	33.4	< 28.9	28.9 - 30.8	30.8 - 36.0	36.0 – 37.9	> 37.9
Ca	54.8	6.7	< 3.2	3.2 - 4.7	4.7 - 8.7	8.7 – 10.2	> 10.2
Mg	55.4	4.3	< 3.1	3.1 - 3.6	3.6 - 5.0	5.0 – 5.6	> 5.6
S	56.3	2.4	< 1.4	1.4 - 1.8	1.8 - 2.9	2.9 – 3.4	> 3.4
	t ha^{-1} cycle^{-1}	mg kg^{-1}					
B	58.9	28.4	< 13.9	13.9 - 20.1	20.1 - 36.8	36.8 – 43.0	> 43
Cu	57.0	7.3	< 2.5	2.5 - 4.5	4.5 - 10.1	10.1 – 12.1	> 12.1
Fe	55.6	115.8	< 37.7	37.7 - 70.7	70.7 - 161.0	161.0 – 194.0	> 194
Mn	57.8	77.4	< 19.1	19.1 - 43.8	43.8 - 111.1	111.1 – 135.8	> 135.8
Zn	56.3	18.3	< 10.2	10.2 - 13.6	13.6 - 22.9	22.9 – 26.3	> 26.3
Na	55.1	28.9	< 8.2	8.2 - 16.9	16.9 - 40.9	40.9 – 49.6	> 49.6

Nut: Nutrients and Na; BY_{MP}: Bunch yield at the maximum point of the boundary line equation; OL_{BL}: Optimal level of the BL of nutrients and Na; DEF: deficient; TSF: tending to sufficient; SUF: sufficient; H: high; and TEX: tending to excessive.

In an analogous way, discrepancies were observed in other species, for example, displacement of ranges was observed for *Opuntia ficus-indica*, as Blanco-Macías et al. (2010) in soil with twice the organic matter (OM) and K contents, two and a half, eleven and five times more P, Ca and Mg, respectively, and more favorable climate to the species adjusted ranges with doubled values for P, higher values for K and with lower limits for Ca and Mg coinciding with the upper limits adjusted by Alves et al. (2019). However, Rodrigues Filho et al. (2021b) found similar optimal limits when they adjusted ranges for 'Prata-Anã' banana in more fertile soil in Ceará compared to Bahia, but with climatic differences.

The amplitudes of the optimal ranges varied with the method (SR, BL and MCh). Without detailing, the amplitudes were lower for K, Mg, Cu, Mn, Zn and Na and higher for N, P, and S (Table 5), compared to those reported by Silva (2015), but smaller for K (Rodrigues Filho et al., 2021b). However, Silva (2015) worked with data from 52 plantations of 'Prata-Anã' banana, which in itself may represent high heterogeneity, and did not use the correction factor (k) to reduce the amplitude (Alves et al., 2019) in the case of nutrients with high variability in tissues, micronutrients with CV greater than 20%. The greater amplitude observed for N, P and S is associated with the fertilizers for organic management, highlighting the contribution of manure as a source of these nutrients (Lédo et al., 2021) between plots with and without fertilization. The lower amplitude of the values reflects the lower variability of edaphoclimatic and production conditions, increase the reliability (Serra et al., 2010) and validate adjustments that reflect site-specific conditions (Rodrigues Filho et al., 2021a). The recommendations are more accurate with reduction in amplitude compared to the literature. However, higher amplitudes negatively influence interpretations, but reflect variability related to the environment, management and genotype (Gott et al., 2014).

Ratifying, in the present study, the data came from an experiment with doses of fertilizer for organic management. Thus, increased soil fertility resulting from this practice favored the elevation of the limits and the narrowing of the ranges of the reference values, in addition to genotypic differences (Silva et al., 2014), corroborating Gott et al. (2014), who found influence of soil fertility correction on leaf nutrient contents in maize.

Table 4: Mathematical chance (MCh) for different classes of leaf nutrient contents of 'BRS Platina' banana in improved fertility soil. Guanambi, BA.

Nut	CL[1]	LL_i	UL_i	OL_{MCh}	BY_i	P1[3]	P2[4]	MCh	Nut	LL_i	UL_i	OL_{MCh}	BY_i	P1[3]	P2[4]	MCh
		----- g kg^{-1}-----			t ha^{-1}	----%----		t ha^{-1}		-----mg kg^{-1}------			t ha^{-1}	-----%-----		t ha^{-1}
Nitrogen	1	36.7	38.9		42	0	0	0	Boron	36.3	39.9		48.3	18.8	60	16.2
	2	34.5	36.7		40.9	0	0	0		32.6	36.3		46.6	12.5	40	10.4
	3	32.3	34.5		42.6	6.3	25	5.3		28.9	32.6		45	25	36.4	13.6
	4	30.1	32.3	29	47	25	57.1	17.8		25.2	28.9	28.9	41.9	0	0	0
	5	27.9	30.1		45.4	31.3	38.5	15.7		21.5	25.2		44.4	18.8	30	10.5
	6	25.7	27.9		46.3	31.3	38.5	16		17.9	21.5		45.1	25	36.4	13.6
	7	23.4	25.6		45.8	6.3	33.3	6.6		14.2	17.8		40.9	0	0	0
Phosphorus	1	2.9	3.1		41.7	0	0	0	Copper	13.2	14.8		42.1	0	0	0
	2	2.7	2.9		42.4	0	0	0		11.7	13.2		39.9	0	0	0
	3	2.5	2.7		39.9	0	0	0		10.2	11.7		42.9	0	0	0
	4	2.3	2.5	2.2	47	25	57.1	17.8		8.6	10.1	6.3	43	12.5	28.6	8.1
	5	2.1	2.3		45.4	37.5	40	17.6		7.1	8.6		44.6	12.5	22.2	7.4
	6	1.9	2.1		46.1	31.3	35.7	15.4		5.5	7.1		47.2	56.3	56.3	26.6
	7	1.6	1.8		46.5	6.3	33.3	6.7		4	5.5		45	18.8	30	10.7
Potassium	1	38.5	40.3		42.5	0	0	0	Iron	267	303.2		41.6	0	0	0
	2	36.8	38.5		41.4	0	0	0		230.7	267		44.6	0	0	0
	3	35	36.8		42.3	6.3	20	4.7		194.5	230.7		48.8	6.3	100	12.2
	4	33.2	35	33.2	46.1	37.5	46.2	19.2		158.2	194.5	122	43	6.3	12.5	3.8
	5	31.5	33.2		45.7	37.5	37.5	17.1		122	158.2		46.4	37.5	50	20.1
	6	29.7	31.5		47.8	12.5	50	11.9		85.7	122		45.2	37.5	35.3	16.4
	7	27.9	29.7		45.6	6.3	50	8.1		49.5	85.7		44.1	12.5	22.2	7.3
Calcium	1	10.9	12		46.1	0	0	0	Manganese	174.3	199.6		47	6.3	50	8.3
	2	9.7	10.8		40.1	0	0	0		149	174.3		46.8	6.3	50	8.3
	3	8.6	9.7		42.3	0	0	0		123.7	149		42.4	0	0	0
	4	7.4	8.5	6.2	43.7	12.5	33.3	8.9		98.4	123.7	98.4	44.7	25	44.4	14.9
	5	6.2	7.4		46	37.5	46.2	19.1		73.1	98.4		46	25	50	16.3
	6	5.1	6.2		45.7	31.3	33.3	14.8		47.8	73.1		43.7	18.8	18.8	8.2
	7	3.9	5.1		47.7	18.8	60	16		22.5	47.8		45	18.8	27.3	10.2
Magnesium	1	5.9	6.3		42.3	0	0	0	Zinc	59.2	67		43.5	0	0	0
	2	5.4	5.9		38.6	0	0	0		51.3	59.1		0	0	0	0
	3	5	5.4		42.8	6.3	12.5	3.8		43.5	51.3		46.1	0	0	0
	4	4.6	5	4.1	43.3	6.3	20	4.8		35.7	43.5	16.1	39.8	0	0	0
	5	4.1	4.5		45.1	31.3	45.5	17		27.9	35.7		40.4	0	0	0
	6	3.7	4.1		46.2	43.8	36.8	18.6		20.1	27.9		40.6	0	0	0
	7	3.2	3.7		48.2	12.5	66.7	13.9		12.2	20		46.6	100	47.1	32

Continue...

Table 4: Continuation.

Nut	CL [1]	LL_i	UL_i	OL_{MCh}	BY_i	P1 [3]	P2 [4]	MCh	Nut	LL_i	UL_i	OL_{MCh}	BY_i	P1 [3]	P2 [4]	MCh
		----- g kg^{-1}-----			t ha^{-1}	----%----		t ha^{-1}		-----mg kg^{-1}------			t ha^{-1}	-----%-----		t ha^{-1}
Sulfur	1	3.2	3.5		47.8	12.5	66.7	13.8	Sodium	72.9	82		45	0	0	0
	2	2.9	3.2		44.2	12.5	25	7.8		63.8	72.9		39.9	0	0	0
	3	2.6	2.9		45	12.5	40	10.1		54.7	63.8		0	0	0	0
	4	2.3	2.6	2.3	44.3	25	26.7	11.4		45.6	54.7	27.4	42.6	0	0	0
	5	2	2.3		45.4	18.8	33.3	11.4		36.5	45.6		43.2	12.5	22.2	7.2
	6	1.7	2		45.1	12.5	28.6	8.5		27.4	36.5		47.3	50	47.1	22.9
	7	1.4	1.7		44.8	6.3	50	7.9		18.3	27.4		44.3	37.5	33.3	15.7
CV (%)	BY		N	P	K	Ca	Mg	S		B	Cu	Fe	Mn	Zn	Na	
	4.4		8.6	8.4	5.8	17.7	9.4	19.4		25.3	21.7	29.9	49.9	11.3	25.2	

[1]CL: Classes; LL_i: Lower limit of class i; UL_i: Upper limit of class i; OL_{MCh}: optimal level within the optimal range (median of the values in the range) of the MCh; BY_i: Bunch yield of plots in class i; [3]P1: probability or frequency of high-yielding plots in class i relative to the total of high-yielding plots; [4]P2: probability or frequency of high-yielding plots in class i relative to the total plots in class i. Nut: Nutrients and Na; MCh: mathematical chance of the factor in class i; CV: coefficient of variation for yield ≥ 47.43 t ha^{-1} and nutrients.

Table 5: Optimal ranges and levels for macronutrients (g kg^{-1}), micronutrients and Na (mg kg^{-1}) adjusted by different methods for 'BRS Platina' banana and comparison with the literature.

Methods	N	P	K	Ca	Mg	S
SR	26.7 – 34.2	1.9 – 2.5	31.2 – 36.6	5.6 – 8.4	3.9 – 4.9	2.0 – 3.0
BL	23.2 – 35.4	1.7 – 2.4	30.8 – 36.0	4.7 – 8.7	3.6 – 5.0	1.8 – 2.9
OL_{BL}	29.3	2.1	33.4	6.7	4.3	2.4
MCh	25.7 – 32.3	1.9 – 2.5	31.5 – 35.0	5.1 – 7.4	3.7 – 4.5	2.0 – 2.6
OL_{MCh}	28.9	2.2	33.2	6.2	4.1	2.3
CLz	27.7	2	32.2	5.3	4	2.1
SR* (Silva, 2015)	25 – 29	1.5 – 1.9	27 – 35	4.5 – 7.5	2.4 – 4.0	1.7 – 2.0
BL** (Rodrigues Filho et al., 2021b)	19.9 – 22.1	1.4 – 1.6	24.0 – 31.3	5.3 – 5.8	2.1 – 2.7	1.3 – 1.5
Methods	**B**	**Cu**	**Fe**	**Mn**	**Zn**	**Na**
SR	21.8 – 32.5	5.5 – 9.4	87.7 – 165.5	54.9 – 101.8	15.3 – 26.2	22.6 – 43.4
BL	20.1 – 36.8	4.5 – 10.1	70.7 – 161.0	43.8 – 111.1	13.6 – 22.9	16.9 – 40.9
OL_{BL}	28.4	7.3	115.8	77.4	18.3	28.9
MCh	17.9 – 39.9	5.5 – 7.1	85.7 – 158.2	73.1 – 123.7	12.2 – 20.0	18.3 – 36.5
OL_{MCh}	28.9	6.3	122	98.4	16.1	27.4
CLz	21.9	5.3	87	44.1	15.3	23.4
SR* (Silva, 2015)	12 – 25	2.6 – 8.8	72 – 157	173 – 630	14 – 25	20 – 60
BL** (Rodrigues Filho et al., 2021b)	13.7 – 16.4	4.4 – 5.2	39 – 55	64 - 91	12.4 – 14.5	-

SR: sufficiency range; BL: boundary line method; OL_{BL}: Optimal level by the BL method; MCh: mathematical chance method; OL_{MCh}: optimal level by the MCh method; CLz: critical level by the reduced normal distribution method; *Optimal range by SR method for 'Prata-Anã' banana in northern Minas Gerais (Silva, 2015). **Optimal range by the BL method for 'Prata-Anã' banana cultivated in Ponto Novo, BA (Rodrigues Filho et al., 2021b).

The optimal ranges obtained by the SR, BL and MCh methods converged considerably with each other. However, for N, P, Ca, Mg, S, Cu, Fe and Na, they can be classified in the following decreasing order for the amplitude of their values: BL > SR > MCh, justified by the particularities of the methods and the variability of the population considered.

Critical and Great Levels

The CLz values were located, in most cases, within the intervals and close to the lower limits of the optimal range of SR, MCh and BL. SR showed a higher frequency of cases in which the CLz values were below the lower limit of the optimal range. When compared to the CLz determined by Carvalho Júnior et al. (2019), for ‘Prata-Anã’ banana under irrigation in northern Minas Gerais, the levels were lower for K, Ca, Cu, Mn, Zn and Na, and higher for N, P, Mg, S, B and Fe. On the other hand, the optimal levels of MCh (OL_{MCh}) and Boundary Line (OL_{BL}), of all nutrients, were above the CLz values and within the optimal range of SR, MCh and BL, as they were calculated for a more homogeneous population and represent the median and maximum point of the optimal range of these last two methods mentioned, respectively.

CONCLUSIONS

The reference values adjusted by the SR, CLz, BL and MCh methods can be reliably used to interpret the leaf analysis of ‘BRS Platina’ banana in improved fertility soils. MCh provides narrower sufficiency ranges, whose optimal intervals and levels are, respectively, in g kg^{-1}: N, 25.7-32.3/28.9; P, 1.9-2.5/2.2; K, 31.5-35.0/33.2; Ca, 5.1-7.4/6.2; Mg, 3.7-4.6/4.1; S, 2.0-2.6/2.3; and in mg kg^{-1}: B, 17.9-39.9/28.9; Cu, 5.5-7.0/6.3; Fe, 85.7-158.2/122.0; Mn, 73.1-123.7/98.4; Zn, 12.2-20.0/16.1; Na, 18.3-36.5/27.4.

AUTHOR CONTRIBUTION

Conceptual Idea: Donato, S.L.R.; Neves, J.C.L.; Methodology design: Donato, S.L.R.; Neves, J.C.L.; Marques, P.R.R.; Data collection: Marques, P.R.R., Data analysis and interpretation: Santos, M.A.; Donato, S.L.R.; Neves, J.C.L.; Marques, P.R.R.; Pereira, M.C.T.; Rodrigues, M.G.V., and Writing and editing: Santos, M.A.; Donato, S.L.R.

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